HATFIELD

The Value of

"Activated Sludge" as a Fertilizer

Chemistry

M. S.

1915

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THE VALUE OF "ACTIVATED SLUDGE" AS A FERTILIZER

BY

WILLIAM DURRELL HATFIELD
B. S. Illinois College, 1914

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

IN CHEMISTRY

IN

THE GRADUATE SCHOOL

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THE GRADUATE SCHOOL

June 5 1915

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY WILLIAM DURRELL HATFIELD

ENTITLED THE VALUE OF "ACTIVATED SLUDGE" AS A FERTILIZER.

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science

Edward Bartow,
In Charge of Thesis

W. A. Noyes
Head of Department

Recommendation concurred in:*

Committee on Final Examination*

*Required for doctor's degree but not for master's.

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INTRODUCTION

In sewage purification solids are separated by settling or precipitation processes sometimes accompanied by digestion which reduces the amount of the solids. The solid matter, which contains from 80 to 95 per cent of water, is termed sludge. The disposal of the sludge is an important part of sewage purification. From an economic point of view, present modes of sludge disposal are wasteful, since the sludge contains valuable fertilizing constituents which are almost universally lost. Many economists have calculated the appalling waste of nitrogen and phosphorous in terms of dollars and cents, and in terms of the number of acres that could be manured by it, and the bushels of grain which could be grown by its application to the soil. Nevertheless, we find very little sludge used, because it has not proved practically to be what its chemical composition would predict. There is also another phase to the question. The present methods of disposal are not only wasteful from an economic point of view but also are of great expense to the sewage purification plant even though it is disposed of in the cheapest manner possible. It may truthfully be said that the real problem of sewage purification plants is the sludge problem.

In studying a new process of sewage purification it is necessary to make a careful study of the sludge produced. Much experimental work is now being done in England and the United States on a new sewage purification process "aeration in presence of

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activated sludge". With the advice of Dr. G. J. Fowler of the University of Manchester, Dr. Edward Bartow and F. W. Mohlman are experimenting along the lines described by Ardern and Lockett.*

*J. Soc. Chem. Ind. 33, 523-39, 1122-4. (1914)

A description of their preliminary work has been published.**

**J. of Ind. Eng. Chem. 7, 318. (1915).

A study of the "activated sludge" which is formed by this particular aeration process to find out if it has any value as a commercial fertilizer, has been undertaken. The following outline has been followed:

1. Development of the use of sewage and sewage sludge as a fertilizer.

2. Description of the methods of formation of the various sewage sludges and "activated sludge".

3. Physical properties of "activated sludge" and its treatment to produce a salable product.

4. Chemical analysis of "activated Sludge" including determination of fertilizing constituents and constituents which may lower the fertilizing value.

5. The availability of fertilizing constituents by:

   a. Official methods,

   b. Bacteriological methods,

   c. Pot cultures.

[illegible]

6. Comparison of its composition and value with commercial fertilizers and septic, settling tank, and chemical precipitation sludges.

The present methods of sludge disposal are both wasteful and expensive, not to mention unsanitary in most cases.*

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*"Sewage Disposal", Fuller. 449-50.
"Sewage Disposal", Kennicut, Winslow and Pratt. 167-192. (1912)
"Disposal of Sewage Sludge". Sur. 42, 602. (1912)
"Struggle with Sewage Sludge". Sur. 41, 818. (1912)
Sur. 41, 358.

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1. Sea disposal is the cheapest method for cities on the shores of the oceans or large bodies of water, but there is always the danger that the tide will bring the sludge back. Also it may contaminate fish and spread disease. Calculations show that the cost of disposal is from eight to fourteen cents per ton.

2. Filter pressing is only a preliminary process since it simply reduces the volume and thus makes the sludge easier to handle. It must still be disposed of. The cost of filter pressing is from 9 to 15 cents per ton in case of ordinary sewage sludge and from 15 to 25 cents per ton in case of sewage sludge containing industrial wastes.

3. Centrifugal drying is a new method which is used in a few places. It costs from 35 to 50 cents per ton. Like filter pressing, this is only a preliminary treatment.

4. Heat drying is drying the pressed cake on iron

plates which are heated with steam from the plant. Also in some places hot air is forced through the sludge and the dried sludge faned by it out of the machine.* The cost of heat drying is from

*J. D. Watson. Sur. 45, 55. (1914)

35 to 50 cents per ton.

5. Disposal on land by dumping, trenching, and lagooning, requires large tracts of land which are usually hard to get and expensive. There is also the unsanitary aspect.

6. Air drying requires large tracts of land since the sludge should not be kept more than three inches deep. Temperature is quite an important factor in this method.

7. Destructive distillation is a very expensive method and does not yield a very valuable gas, since its calorific value is low.

8. Grossman's method of distillation with superheated steam produces a very salable sludge which is free from grease and is sterile. There is no available data of its expense and the return from the sale of the sludge.

9. Wet carbonization also is a new method on which there is no data with regard to the expense. It gives a fat - free and sterile sludge.

10. The manurial value of sludge will be discussed in full in the historical sketch and in the account of the experimental work. Let it suffice for the present to say that experience has

shown that its manurial value does not make sludge a marketable product.

I. DEVELOPMENT OF THE USE OF SEWAGE AND SEWAGE SLUDGE AS FERTILIZERS.

During the first half of the nineteenth century sewage disposal became an important and pressing problem in England, because of the density of the population and the smallness of the rivers. Owing to the large quantities of unpurified sewage which the larger cities literally dumped into these small rivers, these soon became so polluted that many writers described them as inky, boiling, stinking masses. This lead to a demand for treatment of the sewage. The first purification or disposal methods used in England were sewage irrigation and sewage farming. The Royal Commission appointed in 1857 to deal with the widespread river pollution, * reported that only by sewage irrigation and farming could the pollution of the streams be prevented, and that in some cases a profit was yielded by this method of disposal. In 1862 a committee of the House of Commons reported that the manurial value of sewage varied greatly, and that financial profit was only possible under favorable conditions. Many cities could not find enough available land, even if suited to sewage farming, to handle their large volumes of sewage. This led to many attempts

*"Principles of Sewage Treatment" by Dr. Dunbar and Calvert, Chap.II "Legal Measures taken by Central and Local Authorities".

[illegible]

to use chemical and biological treatment. In 1877 Frankland experimented with "intermittent filtration", but it fell to men in the United States to develope this method. The most important work done in the United States were the experiments which were carried on at the experiment station erected at Lawrence, Mass. Experiments were made on the coarseness of the sand or gravel in the filters and automatic devices for distributing sewage on the filters. The work at the Lawrence Experiment Station was so successful that Dibdin, in 1896, took up studies with "intermittent filtration" and called it "bacterial purification". Not until 1898 were these artificial methods of purification officially recognized by English authorities. Since this time many improvements have been made by the introduction of settling tanks, Imhoff tanks, sprinkling filters, contact beds, etc. With the introduction of these modern methods of sewage disposal, sewage farms are gradually disappearing since it has been found that ho profit can be expected from them, and that the cost of such farms is greater (in most cases) than when sewage is treated by more modern methods.

The largest and best managed sewage farms* are those

*Monthly Bulletin of the State Board of Health of Mass. Dec. 1913. "Fertilizing Value of Sewage and Sewage Sludge" by H. W. Clark.

of Paris and Berlin. These farms, in 1907, covered 15,000 and 35,000 acres, respectively. According to Calumette the profits

are small and the process, as a whole, a costly one. In 1906 the total operating cost of the Berlin farm was $700,000, and the receipts were $750,000. The capital sum expended up to 1907, however, aggregates $12,000,000. The cost of operation for that year was $16.40 per million gallons of sewage treated; the receipts were $17.60 per million gallons, while the interest on the invested capital at 3 1/2% was $9.80 per million gallons, showing instead of a profit an actual loss of $8.60 per million gallons treated.

Calumette, after studying the Paris farms, concluded that they will be ultimately abandoned, and Dunbar believes that at Berlin artificial filters will some day take the place of the vast sewage farms now in use.

In all modern processes of sewage treatment a vast amount of sludge is precipitated or settled. Naturally the question of the utilization of this sludge as a fertilizer was at once raised. A supposedly careful study of this question was made by the British Royal Commission on Sewage Disposal, Fifth Report, 1908. After many years of study they concluded that while sludge undoubtedly has a fertilizing value, the value is small compared to the gross mass of the sludge, and consequently the value depends on the cost of carriage. They made a number of experiments on a large scale using seven different sludges. These experiments and the Commissions conclusions are as follows:

[illegible]

1. Sludge was applied to plots of ground in amounts giving an equivalent of 20 lbs. of nitrogen and 18 lbs. of phosphorous as P_2O_5 per acre. Plots were also fertilized with equivalent amounts of $(NH_4)_2SO_4$ and superphosphate. The crop grown was turnips. The sludge treated plots yielded poorer crops than the untreated plots, while the commercially fertilized plots yielded 4 1/2 tons more than the untreated plots.

2. Similar to (1) only that an equivalent of 40 lbs. of nitrogen was added. In this case wheat and corn were grown. The results showed that the sludge had no effect on the corn but in the case of wheat a much larger straw was formed.

3. Sludge was applied to grass land. Results showed that the treated plots were poorer than the untreated plots.

In the report it is frequently stated that the season was exceptional, and that the results should not be taken as conclusive.

H. Maclean Wilson of the West Riding Rivers Board*

*Report upon Sewage Sludge as a Manure" West Riding Rivers Board, published at Wakefield Dec. 1913.

states that these experiments are opposed to practical experience, in view of the fact that many farmers and market gardeners near the large cities continue to use sludge and can show that it has a marked effect on their crops, whether of hay, grain, roots, rhubard, or vegetables. He also claims that foreign agricultur-

ists are buying large quantities of England's sludge in spite of the cost of carriage. Northern France, Argentine, and the United States make the largest purchases. Wilson says "If sludge is found so valuable in these countries it should be well worth trying at home where the price would be much lower." It is safe to say that not one percent of England's sewage sludge is used as a fertilizer. The Sewage Commission claims* this to be

*Report of British Royal Commission on Sewage Disposal. Fifth Report 1908.

due to the unavailability of the nitrogen and phosphorous, which they believe to be due to the large percent of grease present in sludge. It has been claimed byythe early investigators that this grease forms an impervious covering, thus keeping water, air, and micro-organisms from the nitrogen and phosphorous. However, in light of recent investigation, this is not entirely correct. The physical character of the applied sludge is a very important factor and apparently no data is given of the physical characteristics of the sludge they used.

There are in England several municipalities* with an

*Report of the West Riding Rivers Board, Wakefield, Dec. 1913.

unusually rich sewage, which are able to sell their sludge or part of it, and a few which add lime or other constituents to the sludge in order to make it marketable. One of the three

disposal plants at Glasgow - a chemical precipitation plant - dries and grinds its sludge and sells it under the name of Globe Fertilizer at $2.40 per ton in bulk or $3.40 per ton in bags.

Bedford, England, has a sewage containing woolen mill wastes. The grease is extracted and the sludge powdered. It is quite marketable.

At Oldham, England, grease is removed by the Grossman's process of steam distillation. The resulting sludge is mixed with $NaNO_3$ or kainite and makes an excellent fertilizer.

Kingston on Thames sells a chemically precipitated sludge under the name of "Native Guano".

Hebden Bridge sludge is sold in granular form.

Huddersfield uses the wet carbonizing methods and sells the resulting sludge in a powdered form.

In each of the above cases the sludge is powdered and in a few the grease is removed. In the vast majority of cases, however, sludge is only prepared in the form of pressed cake or filter dried, containing from 60 to 70 percent moisture. In this condition it is not easily applicable to the ground, and the farmers will not carry it away. Such sludge, moreover, is very likely to contain seeds of many troublesome weeds not to speak of tomato, raspberry, strawberry and other fruit seeds.

In opposition to these facts the chemical analysis of sludges indicate that they are valuable and it has been surprising that the farmers have not been anxious to get them, since their

cost was so low and the supply so plentiful.

Naylor in an article entitled, "The Struggle with Sewage Sludge"* states, after quoting analysis of commercial

*Sur. 41, 818. (1912).

fertilizers, manures, and sewage sludge, that dried sludge should have a value of $7.50 to $10.00 per ton, and to be easily capable of enrichment by ammonium sulfate and ground bones. But he adds, "it has been recently pointed out by Dr. E. J. Russel that a soil must be considered from three points of view: (1) its store of plant food actual and potential, (2) its physical properties, and (3) the rate at which potential food can be converted into actual food. What one must consider in dealing with the value of a manure or fertilizer in a soil is its ease of decomposition. In spite of alluring advertisements and tempting analyses, farmers do not take even ordinary dried sludge away as voraciously as one would expect." The cause of this Naylor attributes to the presence of grease. The removal of grease, he says, is absolutely necessary before sewage sludge will be accepted as a manure worthy of the consideration of the agriculturist. In the article three methods of removing grease are mentioned,

1. solvent degreasing,
2. distillation by superheated steam,
3. dry distillation.

In (1) the solvents used are both expensive and danger-

ous; the apparatus is also expensive and the slightest leak must be guarded against. It is improbable that an economical method of solvent degreasing will be perfected in many years.

Dr. Grossmann's process at Oldham, England, is the best example of distillation with superheated steam. In Dr. Grossmann's article* on his process is a very detailed discussion

*Sur. 41, 358.

of the great expense of all other methods of sludge disposal, but not a word does he mention in regard to the costs of his own process, which consists in (1) drying, (2) powdering, (3) acidifying and distilling with superheated steam, (4) again drying. Grossmann claims that this produces a sterile sludge which will not clog the soil.

(3). Dry distillation or "wet carbonization" is the carrying over of grease by the hot gases and steam generated from wet sludge. This method produces a dried, powdered, fat free, sterile sludge of high manurial value. The average analysis giving 4.41 to 5.28% nitrogen as NH_3 on dried product.

Watson*, mentions with approval the process at Dublin,

*Sur. 45, 55. (1914).

Ireland. Here "brewers yeast" is introduced into the sludge to permit rapid fermentation and separation of water. The separated water is drawn off and the remaining mass dried by hot air at

450°F., powdered and blown out of the machine. No analysis of this sludge is found in the article.

H. W. Clark* draws the following conclusions from his

*Monthly Bulletin of the State Board of Health of Massachusetts, December 1913.

study of the literature and his own work:

1. That sewage farming is rapidly being abandoned in favor of modern methods of purification.

2. In order to reclaim the valuable material from sludge it must be dried, degreased, and powdered. When the grease is extracted by any known method this procedure is costly. The sludge has a value, however, and as the processes of treatment are improved, sewage sludge will become of greater agricultural value than it is at present.

In an article on fresh and decomposed sludge** H. Bach

**Eng. Record, 68, 331. 1913.

and L. C. Frank discuss the composition of the two forms of sludge. They conclude that the physical quality or character of sludge is as important as the nitrogen content. They show that in fresh sludge the grease and fibrous material cause the earth to become impervious to rain and probably does more harm than good as a fertilizer. On the other hand, decomposed sludge contains less fat and is not so fibrous. In addition, the fat remains very finely

divided and uniformly distributed through the mass of sludge, and since the sludge itself is porous, this finely divided fat is not an appreciable hindrance to percolation. The sludge drys quickly and remains porous when dry. Hence, when it is used as a fertilizer the porosity of the ground is not effected, so that moisture and air can penetrate everywhere and come in contact with the nitrogenous material.

The most recent work is recorded in an article entitled "The Utilization of the Nitrogen and Organic Matter in Septic and Imhoff Tank Sludges" by C. B. Lipmann and P. S. Burgess.* In their

*Bulletin 250 of the Agricultural Experiment Station, Berkeley, California, April 1915.

experiments they used a new and very interesting method for the determination of the available nitrogen in sludge and organic fertilizers. This new method was introduced because the arbitrary chemical methods of determining "available nitrogen" seem to have but little relation to the actual conditions, so far as field conditions are concerned. Their method consisted in determining the degree to which the nitrogen in sludges and in other organic nitrogen fertilizers is changed to nitrates by the nitrifying bacteria of soils. Their method consisted in inoculating three different soils with nine different sludges and six different forms of organic nitrogen fertilizers, incubating for a definite period and determining the percent of total nitrogen changed to

nitrates. A table showing a comparison of availability of the nitrogen in sludges and organic fertilizers, as determined by their experiments is quoted below.

No.	Description of source of sludge. (Dried and powdered).	Davis soil % N_2 available	Oakley soil % N_2 available	Anaheim soil, % N_2 available
1.	Orange City Imhoff tank	32.50	32.30	27.20
2.	Fullerton Imhoff tank	43.90	43.50	40.60
3.	Anaheim Municipal tank	32.40	36.00	40.20
4.	Lindsay septic tank	28.70	18.00	18.80
5.	Pasadena Imhoff tank	38.00	28.20	35.70
6.	Orange City Imhoff tank	25.70	21.40	15.70
7.	Worcester, Mass. Imhoff tank	26.60	12.40	34.50
8.	Cleveland, Ohio, Imhoff tank	32.90	8.30	44.10
9.	Chicago. Ill. stock yards Imhoff tank	24.50	9.80	10.10
10.	Dried Blood	12.79	0.00	4.05
11.	High grade tankage	16.21	0.00	3.95
12.	Low grade tankage	27.39	22.70	43.89
13.	Fish guano	15.11	trace	4.65
14.	Cotton seed meal	14.18	2.00	21.45
15.	Goat manure	4.89	3.50	10.39

When they are compared on the basis of "availability", used in the sense of nitrifiability, nitrogen from sludge is greatly superior to that from other nitrogenous materials. Low grade

tankage is the only material of the six employed besides the sludges that belongs in the same class with the sludges from the point of nitrifiability. The different soils differ greatly in the nitrification of dried blood and tankage, while in sludges the results are more uniform. It would seem that sludges were far superior to all other nitrogenous organic fertilizers except low grade tankage.

II. THE FORMATION OF THE VARIOUS KINDS OF SLUDGES.

In the process of plain sedimentation the sewage passes through an especially constructed tank at a velocity which should not exceed 0.5 inch per second and preferably should be lower. This allows a large part of the organic matter, which is not in solution, to settle. At the Lawrence station 33 per cent of the total suspended matter is settled, including 30 to 50 percent of the fats. The approximate composition of this sludge is:

Moisture	90-95%
Specific Gravity	1.02
Dry Basis	
Organic matter	40-50%
Fats	9-20%
Nitrogen	1-3%

In septic tanks the sludge which settles is allowed to undergo anaerobic decomposition whereby it is converted into a non-odorous and stable substance which ordinarily can be more

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easily disposed of than without decomposition. This decomposition causes an increase in the mineral content and a decrease in the percent of organic matter, fats, nitrogen, and phosphorous. It was shown by Bach and Frank* that this sludge was superior to fresh

*Eng. Record, 68, 331.

sedimentation sludge for use as a fertilizer chiefly because of its physical character.

Chemical precipitation consists in adding to the sewage certain chemicals which will produce a gelatinous precipitate. This precipitate envelops much of the suspended organic matter and carries it down in the form of chemically precipitated sludge. This sludge is filter pressed and either dumped in low land or disposed of in the cheapest way possible. In a few cases it is sold as a fertilizer. Chemically it does not differ greatly in composition from the above sludges.

The "activated sludge" with which this thesis deals, is formed by blowing air through sewage until it is completely nitrified. The time required for this first complete nitrification is from 15 to 33 days.** The purified sewage is allowed to

**J. Ind. and Eng. Chem. 7, 318. (1915)

settle and the supernatant liquid is siphoned off. Fresh sewage is added and the mixture again aerated as above until nitrifica-

tion is complete. In this second case complete nitrification requires only four days. Again the mixture is allowed to settle and the supernatant liquid drawn off and fresh sewage added. By repeating this process the time of purification or complete nitrification is reduced to from four to six hours. This decrease in the time of nitrification is due to the presence of "activated sludge" which is formed. It is impossible to state at present exactly what causes the formation of this sludge. The presence of organic matter and an excess of air make conditions optimum for a flora of aerobic organisms and micro-organisms. These organisms, the oxidizing property of the air, and the coagulative property of the sludge, all must tend not only to carry down the suspended matter but also to stablize the soluble matter and carry down a large percent of bacteria. Since this sludge is developed under strictly aerobic conditions it does not possess any unpleasant odor and consequently is in no way obnoxious to handle.

III. THE PHYSICAL PROPERTIES OF "ACTIVATED SLUDGE" AND ITS TREATMENT TO PRODUCE A MARKETABLE PRODUCT.

As has been shown above, the physical properties of a sludge are almost as important as the chemical composition. Consequently, these properties were the first to be studied.

"Activated sludge" as it settles from the purified sewage, when the air current is stopped, is a brownish, odorless, homogeneous, flocculent, finely divided mass. This was quite a

contrast to the Urbana septic tank sludge, which was studied. The septic tank sludge was coarse, black, and very sour smelling. On filtering the "activated sludge" it very much resembled plain black mud. The filtered "activated sludge" dried on a steam bath still had little or no odor. The dried sludge was easily ground in a mortar to a fine powder. The sludge in this form had a strong organic nitrogenous odor much resembling that of dried blood. In this powdered form, the sludge is very porous and shows no trace of greasiness. Septic tank sludge, on the other hand, when dried as above, was not easily pulverized. It was of a sticky, greasy nature, adhering in small masses to the mortar and pestle. It was impossible to grind it into a fine powder as was the case with "activated sludge". The specific gravity of the two sludges was nearly the same, that of the "activated sludge" being 1.03 and that of the septic tank sludge being 1.02. The "activated sludge" rapidly settles, is easily dried, and easily pulverized into a product which, if valuable as a fertilizer, would be easily handled, would not clog the ground, and should be very marketable. Repeated examinations from time to time of different specimens of activated sludge showed it to be constant in its physical properties.

IV. CHEMICAL ANALYSIS OF "ACTIVATED SLUDGE" INCLUDING DETERMINATION OF FERTILIZING CONSTITUENTS AND CONSTITUENTS WHICH MAY LOWER THE FERTILIZING VALUE.

The methods of analysis used in this work were those

suggested by Dr. Lederer.* In some cases it was deemed best to

*Manuscript entitled "The Analysis of Sewage Sludge and Mud Deposits" presented to the Committee on Standard Methods of Water Analysis of the American Public Health Association, to be added to Standard Methods.

alter these methods as the work proceeded.

1. Specific gravity was determined in the usual way by the weight of distilled water displaced.

2. Moisture was determined on 25 grams of sludge by evaporating in a nickle dish on a steam bath and then drying in an oven at 100°C to constant weight.

3. Volatile and fixed matter was determined by ignition of the dried sludge.

4. Organic nitrogen was determined on the dry sample by digesting in a Kjeldahl flask with concentrated sulfuric acid and a crystal of copper sulfate. After digestion the ammonia was distilled over, according to the usual method, and collected in a 250 cc. measuring flask. An aliquot part of this was then nesslerized and total nitrogen calculated. Later in the work, in order to check this method the distilled ammonia was caught in standard acid, the excess acid titrated with standard alkali, and nitrogen calculated from the standard acid neutralized by the ammonia.

5. Phosphorous was determined by methods given in Bulletin 107, 2-3, U. S. Department of Agriculture for total

[illegible]

phosphorous in fertilizers. Both gravimetric and volumetric methods were used.

6. Fats were at first determined by Lederer's method which consisted in acidifying and drying the sludge, then extracting three times with hot ether and determining the fats extracted. This being rather a rough method, it was decided to use a soxhlet extracter allowing it to extract for three hours (20 to 30 extractions). Very late in our work, by accident, some extractions ran all night (16 to 20 hours) and it was found that the grease content was over twice as high as had been previously calculated. Sixteen hours are the minimum that the extraction should run.

7. Bio-chemical oxygen demand. -- This determination, though of no value from a fertilizing standpoint, is of interest in comparison to that of septic sludge. One-tenth to one gram of the wet sludge was diluted to one liter with aerated distilled water of known dissolved oxygen content. This mixture was then incubated for five days at 20° and then after careful shaking a dissolved oxygen determination made on the mixture. The loss of dissolved oxygen is then calculated in grams per hundred grams or milligrams per thousand.

The analysis of the first sample of "activated sludge" which was collected January 21, 1915 from a three gallon bottle which had been aerated and changed according to the process described above for "aeration of sewage in contact with activated sludge" is given below. This bottle was started November 2, 1914.

Moisture	95.54%
Dry matter	4.46
	100.00%

Volatile matter (dry basis)	74.8%
Mineral matter " "	25.2
Total nitrogen (N_2)	5.6

Analysis "activated sludge" collected February 10, 1915 from the same bottle as the first sample.

Moisture	95.50%	
Volatile matter	75.00	
Total nitrogen (N_2)	6.3	(dry basis)
Phosphorous (P_2O_5)	3.31	" "
" "	1.44	" "
Fat (3 hrs. extraction)	4.0	" "

It was suggested that we might be losing ammonia nitrogen by evaporation on the steam bath or by the liquid which was drawn off by suction, so comparative analyses were made as follows:

Sludge - designated (Sampled March 5, 1915)

A, was dried on steam bath as it was collected.

B, was acidified with H_2SO and dried,

C, dried by suction then on steam bath.

The nitrogen content of each was found to be 6.3% and the phosphorous 3.3 as P_2O_5. There was, therefore, no loss on evaporation.

To March 15, 1915 only small quantities of sludge were available. Since then, larger quantities have been available. Many analyses have been made by different methods.

Following is the results of analysis of typical sludge.

Moisture	95.5%
Dry matter	4.5

Analysis of dry sludge.

	Nesslerization	Standard acid
Total nitrogen (N_2)	6.3%	6.43%
Total	Gravimetric	Volumetric
Phosphorous (P_2O_5)	2.97%	2.69%
Ether soluble (three hrs. extraction)	4.00	
Ether soluble (sixteen hrs. extraction)	11.8	

A comparison of the bio-chemical oxygen demand of Urbana septic tank sludge and "activated sludge" showed the following results:

	Oxygen demand mg. per 1000 g.
Urbana septic tank	6544.
Activated sludge	1176.

The "activated sludge" does not easily putrefy and the results of the analysis show it to be very much more stable than the sample of septic sludge.

[illegible]

V. THE AVAILABILITY OF FERTILIZING CONSTITUENTS.

(a) Chemical Methods.

The methods of determining the availability of the elements in a fertilizer, by chemical analyses, are very widely disputed, since they are entirely arbitrary. For example, in Official Methods of Analysis, Bulletin 107, Bureau of Agriculture, two methods are given for the determination of available organic nitrogen: (1) the neutral-permanganate method, and (2) the alkaline-permanganate method. In the New England States officials advocate the alkaline permanganate method; while, on the other hand, in the Southeastern States the neutral permanganate method is preferred. These methods may give entirely different results.

Analysis of "activated sludge" made through the courtesy of Paul Rudnick, according to Bulletin 107, U. S. Dept. of Agriculture, show the different results obtained by these two methods:

Moisture	4.23%
Nitrogen	
Total	6.45
Ins. in H_2O	6.12

Availability	Alkaline Permanganate Method	Neutral Permanganate Method
Inactive water insol. organic N_2	3.39%	0.67%
Active water sol. organic N_2	2.37	5.45
Availability of water insol. org. N_2	44.7	89.0

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Phosphorus	
Total (P_2O_5)	2.14%
Calc. as bone phosphate of lime	4.6
Potash (water sol.)	1.05

According to the alkaline permanganate method, the available nitrogen is below 50 per cent and the sludge would be classed as an inferior ammoniate.

According to the neutral permanganate method the available nitrogen is above 85% and the sludge would be classed as a very satisfactory ammoniate. Such conflicting results make it impossible to truly judge from the chemical analysis the value of "activated sludge" as a fertilizer.

(b) Pot Culture Methods.

The only absolute method for determining manurial value of the sludge is to actually use it as a fertilizer for growing plants. On February 20, 1915, five pot cultures of wheat were started. Each pot was carefully filled so that we knew exactly its contents. Distilled water was used for watering the cultures in order that no plant foods would be introduced by the soluble salts in tap water. The sand used in making up the pots was the purest white sand obtainable. Since nitrogen is the important plant food in the sludge the pots were prepared to contain all the plant foods except nitrogen. To one pot for a check, no nitrogen was added. To the others, nitrogen was added in the form of dried

blood or sludge as shown by the table below.

The contents of the pots were:

Pot number	1	2	3	4	5
	grams	grams	grams	grams	grams
(1) White sand	19,820	19,820	19,820	19,820	19,820
(2) Dolomite	60	60	60	60	60
(3) Bone meal	6	6	6	6	--
(4) Potassium sulfate	3	3	3	3	3
(5) Activated sludge	--	--	20	--	--
(6) Extracted sludge	--	--	--	20	--
(7) Rock phosphate	--	--	--	--	20
(8) Dried blood	--	8.61	--	--	8.61

Each pot contained an equivalent of,

5 tons per acre of dolomite,

1/2 ton " " " bone meal (except 5),

500 lbs. " " " potassium sulfate.

Pot 5 contained 1 1/2 tons of rock phosphate instead of bone meal. This pot contained three times as much phosphorous as the other pots since the phosphate in rock phosphate is not so available as that in bone meal.

Pot 1, the check pot, contained no nitrogen with the exception of 60 milligrams which were added in the bone meal. This small amount was without significance since the same amount was added to the other pots, except 5.

Each of the other pots contained an equivalent of

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

approximately 120 pounds of nitrogen (one ton of sludge) per acre.

Thirty wheat seeds were planted, two seeds in each of fifteen holes, in each pot. In four days the plants were up in each pot and in ten days were five inches high. At the end of eighteen days each pot was thinned to fifteen of the best plants, in most cases leaving one plant to each hole. In twenty days from date of planting there was a marked showing in favor of pots 3, 4, and 5. In twenty-three days the sludge pots 3 and 4 (See Fig. 1) were growing far ahead of 1 and 2, while pot 5 was about as good as 3 and 4. Five was not taken since it contained three times as much phosphorous as did the others and was really not comparable. It was not quite as good as pot 4.

Pot 2, (dried blood and bone meal) grew much slower than the pots 3 and 4 (sludge), while 3 and 4 (dried blood and rock phosphate) grew very well, though it was never quite as good as pots 3 and 4. The reason for the poor showing of the plants in 2 is not known. It might have been due to some reaction between some elements in the bone meal and the dried blood which formed a compound which was toxic to the plants. The results of pot 5 might indicate the excess of phosphorous was an aid to the availability of the nitrogen in dried blood. In thirty days pots 3, 4, and 5, were far ahead of 1 and 2. A light brown mold was appearing on the larger plants. This mold was thought to be due to the dark damp weather. Powdered sulfur was used to fight this

[illegible]

Figure I.

mold. During the fifth and sixth week the plants in the sludge pots, which had grown fully three times as large both in height and in foliage as those in the dried blood pot 2, began to yellow and about half of the foliage died leaving about two healthy stalks to each plant. It would seem that the plants grew so fast at first that they could not support all the foliage which had started. The remaining stalks immediately grew stronger and of a deeper blue green color. The picture (Fig. II) taken after nine weeks growth shows the plants after the stalks were well started.

In fourteen weeks the plants in 3 and 4 began to head and in fifteen weeks there were twenty good heads to each sludge pot. Pot 1 was almost dead, while the plants in pot 2 were 1 1/2 feet high. Pot 5 with the high rock phosphate treatment looked as if it would head in about two or three weeks. There were only seventeen stalks which would head in comparison to twenty on the sludge pots.

When it was first noticed that the sludge cultures were growing much better than the dried blood cultures, fearing that, by mistake, some one of the plant foods had been left out, a second series of cultures was started. In this series the sludge was compared with dried blood and also with equivalent amounts of nitrogen from nitrate of soda, ammonium sulfate and gluten meal. This series contained fourteen pots, to seven nitrogen equivalent equal to an application of twenty grams of

Figure II.

sludge was added and to the other seven an equivalent of thirty grams of sludge was added. This series grew a little faster than the first because of better weather, but showed exactly the same characteristics that the other series showed. The sludge pots were the best. The sodium nitrate, ammonium sulfate, and dried blood cultures did fairly well while the gluten meal was better, but never as good as the sludge pots. Differences are shown in a picture (Figure III) taken of the series when it was five weeks old. The pots in this picture are as follows: 3, sludge; 5, extracted sludge; 7, sodium nitrate; 9, ammonium sulfate; 11, gluten meal; and 13, dried blood. Since the pots with the higher treatment showed no difference from those with the low treatment we had no pictures taken of them.

If one will compare Figure II with Figure III, which was photographed before the yellowing set in, he will see the difference in the strength of the leaves.

The surprisingly rapid growth of the wheat in the sludge cultures must be due to a very available form of nitrogen. It also may be aided by the phosphorous which is present in the sludge. At the time of making the pot cultures we considered only the nitrogen content since phosphorous seemed to be present in too small a quantity to be of value. The cause of the molding of the leaves has not yet been decided. It was quite noticeable that the mold appeared chiefly on the leaves of the rapid growing

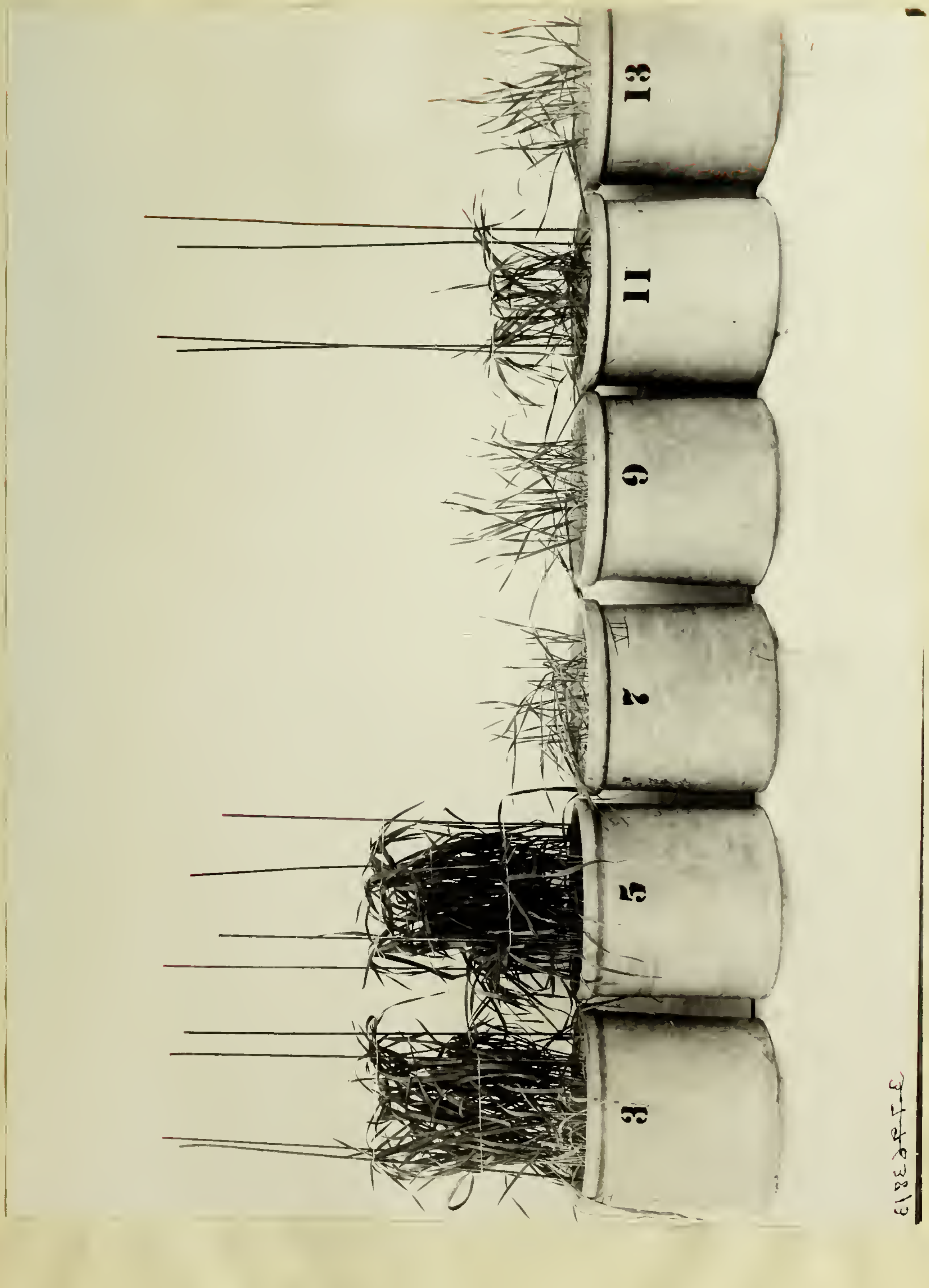

Figure III.

plants. In the first series it only attacked the sludge cultures, but in the second series it also attacked the gluten meal cultures. These rapid growing leaves are naturally more tender than those which grow slowly and consequently are more easily attacked by mold spores. The mold is not due to the sludge because the extracted sludge would probably be sterile. Since the extracted sludge cultures showed the same molding and also since the gluten meal pots had this mold we feel confident that the mold was not due to the sludge.

Since the sludge caused such a rapid growth in the wheat cultures we thought that it might be of use to a truck gardener, to rush his spring crops. A garden containing three plots 2 by 3 feet was started April 24; one plot of the garden was not treated; one was treated with an equivalent to 126 pounds of nitrogen, one ton of sludge per acre, and the third with the same equivalent of extracted sludge. In each of the three plots two rows of radishes and lettuce were planted. The plants in the sludge treated plots came up first, those in the extracted plot a little ahead of those of the unextracted plot. Within two weeks both the lettuce and radishes of the treated plots were twice the size of those in the untreated plots. The crop was planted rather thick so at the end of four weeks the plants were thinned. On pulling the radishes it was found that those from the sludge plots were far ahead of those on the untreated plot. The roots of the radishes from the sludge plots were large and red,

[illegible]

[illegible]

and were quite rounded near the tops while those from the untreated plots had not yet started to swell and had not the good red color. The lettuce plants from the sludge plots were nearly twice as large as those from the untreated plots.

June 1 the six best plants of lettuce and radishes were taken from each plot and photographed (Fig. IV). This picture speaks for itself, showing that in ground as well as in pot cultures the sludge cause an increase in the rate of growth. The radishes from the sludge pots were cut open and some of them eaten to see if this rapid growth had caused a softening or pithyness. They proved to be very crisp and solid, and had a good radish flavor. After photographing the cultures, they were weighed.

Results:

Plot	Treatment	Wt. of Lettuce	Wt. of Radishes
1	none	4.5 g.	23.4 g.
2	sludge	6.3 g.	63.0 g.
3	Extracted sludge	6.8 g.	68.0 g.

This shows an increase in weight, due to the sludge, of 40 percent in case of the lettuce, and of 150 percent in case of the radishes.

These pot cultures and gardening experiments have been very gratifying and it is safe to say that the nitrogen in "activated sludge" is very available and that it is valuable as

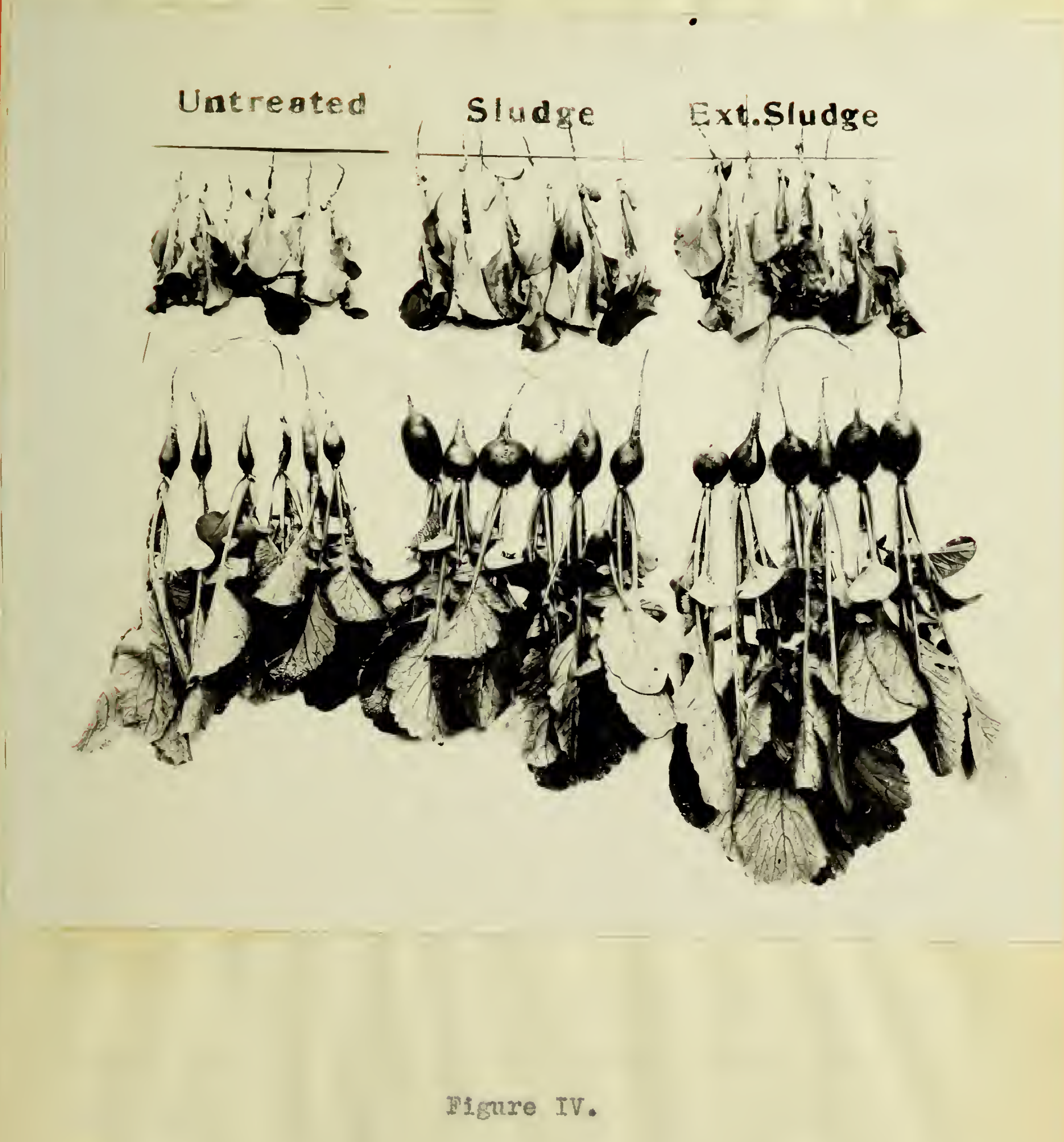

Figure IV.

a fertilizer. The experiments show that the sludge is a better ammoniate than dried blood. The other plant foods in the sludge must be very available since the rapid growth of the sludge cultures cannot be entirely due to the nitrogen.

At one time it was thought that the rapid growth in the sludge cultures was due to a heavy inoculation of bacteria into the pots by the sludge, so we made a number of counts on agar at 20°. No 37° counts were made since we were only interested in the soil bacteria which were present. The counts were made on agar incubated at 20° for twenty-four hours. It was found that one gram of dried sludge contained 340,000 bacteria. There were only two forms present, one a strict aerobe, the other a facultative aerobe. They were both long rods, gram positive, spore formers and formed chains about five or six cells in length. The spores were at the ends or near the ends of the cells. The group numbers were:

111.23230 --

121.23330 --

showing that they undoubtedly belong to the Bacillus subtilis group of aerobic spore formers.

These organisms attack proteins and carbohydrates forming among the end products nitrogen, ammonia, carbon, hydrogen and oxygen. This would indicate that they did play a part in availability but since they would have been killed in the process of ether extraction of the sludge we would expect the extracted

sludge pot to be different from the unextracted. This was not the case so we abandoned this theory.

The count of 340,000 bacteria per gram of sludge is very low in comparison to 70 million which is the count of normal soil.

Nevertheless, the high organic composition of the sludge would favor the growth of many bacteria and since more organic matter was added to the sludge pot in the sludge than was the case in any of the other pots it is possible that the bacterial life was an important factor.

(c) Bacteriological Methods.

While our work was being carried on Burgess and Lipman* of the California Experiment Station published their

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*See page 14.

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article entitled "Utilization of the Nitrogen and the Organic Matter in Septic and Imhoff Tank Sludges". They very kindly consented to make determinations of the value of "activated sludge" according to their methods. Their results are as follows:

VI. COMPARISON AND VALUE OF "ACTIVATED SLUDGE" WITH OTHER FERTILIZERS AND SEPTIC, SETTLING TANK AND CHEMICALLY PRECIPITATED SLUDGES.

The following table* of the average composition of commercial fertilizers show the comparison with "activated sludge".

*Table compiled from Bull. 245, Aug. 1914, Agr. Exp. Sta., Berkeley, California.

	Nitrogen	P_2O_5	K_2O	Value per ton
Nitrate of soda	15-16%	----	----	$48 - $49
Ammonia sulfate	19-22	----	----	30 - 40
Dried blood (high grade)	12-14 1/2	----	----	50 - 55
Dried blood (low grade)	10-11	----	----	40 - 42
Tankage	5- 9	10-15%	----	30 - 50
Dried fish-serap (whale tankage)	12-13	----	----	49 - 55
Cotton-seed meal	6- 7	2	----	
Dried "activated sludge"	6.45	2-3	----	

Schedule* of trade values, 1914 - 15, on which the above values are calculated.

*Bull. 245, 10 (1914) Agr. Exp. Sta., Berkeley, California.

	Cents per pound.
Nitrogen from blood	24.8
Nitrogen from tankage and bone	22.0
Nitrogen from ammonium sulfate	15.7
Nitrogen from nitrate of soda	15.6
Phosphoric acid from tankage	3.6
Phosphoric acid from bone	4.5
Phosphoric acid from bone superphosphate	5.0
Phosphoric acid from rock superphosphate	4.7

These values are based on market quotations at Chicago, New York, and San Francisco.

From the above table of analyses it is seen that "activated sludge" contains less nitrogen than most of the other commercial fertilizers. Its value in dollars per ton would not be so high as those given for the other fertilizers. From the schedule, nitrogen in dried blood is considered of more value than it is in any of the other forms. Now it has been shown by the pot cultures that the nitrogen in "activated sludge" is much more available than that in dried blood and it is consequently, more valuable. Therefore, to take the value in cents per pound of nitrogen in dried blood as a basis on which to calculate the value of "activated sludge" nitrogen, would be very conservative. On this basis, the nitrogen in the sludge is worth $32 per ton. Calculating the phosphorous at four cents per pound we find an added value of the sludge due to the phosphorous to be $2. The

total value of the sludge is then $34 per ton.

W. B. Ruggles in an article in the Engineering Record, 63, 79 (1911) calculated the cost of preparing sludge to be used as a fertilizer, thus:

Cost of filter pressing, per ton	$1.00
Cost of drying, per ton	.35
Cost of grinding, per ton	.16
Cost of bagging, per ton	.15
Total cost per ton	$1.66

This would make a profit of $32.34 per ton of "activated sludge".

It is hardly to be expected that "activated sludge" will bring such a profit but it will certainly sell for considerably more than the cost of production.

It is also of interest to compare "activated sludge" with other forms of sewage sludge.

In the historical sketch it was shown that a number of cities in England were treating their sludge and selling it as a fertilizer. In the following table* the chemical composition

*Report West Riding Rivers Board, Wakefield, Dec. 1913. Sewage Sludges from Different English Towns.

and the selling price of these sludges are given.

Results calculated in dried sludge (100°).

Town	Sewage treatment	Organic matter	N_2 %	P_2O_5 %	K_2O %	Fats %	Dollars per ton
Chorley	Chem. ppt.	--	1.28	0.98	---	---	0.36
Oldham	Grossmann's process	35.	1.5	5.5	.75	---	12.60
Kingston on Thames	Chem. ppt.	50.09	2.76	2.61	---	3.15	15.60
Glasgow	(Globe Fertilizer) Chem. ppt.	43.25	1.65	1.71	---	4.06	2.92
Bradford	Chem. ppt.	---	3.00	1.00	---	17.00	1.44
Urbana	Activated sludge	74.8	6.45	2.5	1.05	11.	---

Since Oldham with a sludge containing 1.5 percent nitrogen and Kingston on Thames with a sludge containing 2.61 percent nitrogen get \$12.60 and \$15.60, respectively, it seems reasonable to believe that "activated sludge" with a nitrogen content of 6.45 percent would bring at least \$34 a ton.

Farmyard manure is sold by the stock yards in our large cities. "Activated sludge" must compete with this manure. Sludges are considered of greater value as shown by the following table:*

*Royal Commission Report V, 1908.
Thorpe's Dictionary of Applied Chem.

Analysis of "activated sludge", sludge and farmyard manure.

	Moisture	N_2	P_2O_5	K_2O	Cost per ton
Farmyard manure	60-70%	2.66	0.96	1.33	$1.65
Sludges	80-90	1.83	1.34	0.75	$15-16
"Activated sludge"	95-96	6.45	2.5	1.05	----

Competition might to a certain degree lower the actual value of "activated sludge", but, since in powdered form it is much easier to handle than farmyard manure, its market price should not be materially lowered.

As was stated once before, transportation is an important factor because of the bulk of the sludge. Since the value is so far above the cost of production the cost of transportation is not so important. The chief market for nitrogen fertilizers is with the truck gardener, for he is the man who must replenish the nitrogen in his soil by artificial fertilizers. He cannot do like the farmer with a thousand acres, that is, replenish the nitrogen in the soil by growing legumes. He must buy a readily available form of nitrogen which he can apply to his ground when it needs it. The large truck gardens are usually near the large cities and since the large cities would be producing the sludge they could easily dispose of it to the nearby truck gardener. The tendency of activated sludge to hurry a crop as shown by our garden experiment should be a recommendation since

the truck gardener wishes just these qualities.

The influence of nitrogen in its various forms as a fertilizer upon plant growth is shown by three striking effects.

First, the growth of stems and leaves is greatly promoted, while an excess of available nitrogen retards that of buds and flowers. Ordinarily, most plants, at a certain period of growth, cease to produce new branches and foliage, and commence to produce seeds or flowers when by that species may be perpetuated. If a plant is provided with too much available nitrogen at this period the formation of flowers may be checked while the activity of growth is transferred back to and renewed in the stems and leaves.

Second, the next effect of nitrogen on plants is to deepen the color of the foliage, which is a sign of increased activity and health.

Third, another effect is to increase the nitrogen content in the plant.

No experiments have been made to determine the proper amounts of "activated sludge" which should be applied to a soil but it is evident that since the nitrogen is very available, too much sludge should not be applied. The rapid growth, at first, in the sludge pots might have been due to an over-dose of sludge. At the same time the dying off of part of the foliage at the end of five weeks would indicate that the nitrogen was exhausted, but since the plants kept on growing and gave good heads, this was

evidently not the case. The frequency and amount of application would of course be altered with each individual case. From the results of the garden it would seem that one ton per acre was not too much of an application.

CONCLUSION

There is a great need of a careful study of the fertilizing value of sewage sludge. At present, very little of the sludge produced is used for fertilizer, but it is clearly shown by a few examples that if sludge is properly treated it should be marketable as a fertilizer. The present methods of sludge disposal are expensive and wasteful, and a better method of disposal and use is desirable.

"Activated sludge" has a chemical composition which indicates that it is far superior to any of the ordinary sewage sludges. A few properly treated sludges have been shown to be salable, therefore there is every reason to believe that there should be a market for dried "activated sludge".

The nitrogen in "activated sludge" is very available, in fact, more available than that in other organic and inorganic nitrogen containing fertilizers.

The physical character of the sludge makes it easy to handle and easy to work up into a marketable product. Also, it is not obnoxious.

The presence of eleven percent of fat does not inhibit the fertilizing value probably because it is very finely divided

and in no way would clog the soil.

The sludge as dried by us contains few bacteria in comparison to soil. Two aerobic spore forming groups were present both probably belonging to the Bacillus subtili group. Other bacteria were evidently killed off by drying. The sludge could easily be sterilized if it was thought best.

A very conservative estimate, taking into consideration not only chemical composition, but the availability of the fertilizing elements in comparison with other well known organic nitrogen fertilizers, places the value of "activated sludge" at thirty-four dollars per ton, while the cost of drying and preparation for market would be $1.66.

The sale of activated sludge should pay a considerable part of the cost of operation of a sewage purification plant using "aeration in contact with activated sludge".

"Activated sludge" with its high fertilizing value may in the near future revolutionize the methods of sewage purification.

We wish to acknowledge the assistance of Professor C. G. Hopkins and Mr. J. C. Anderson for their assistance with the pot cultures; to Mr. Paul Rudnick and Mr. W. D. Richardson for checking analyses of sludge; to Mr. F. W. Mohlman for the materials used; and Edward Bartow for suggesting the topic and for his assistance in carrying on the work.

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